

Universality of the small-scale dynamo mechanism

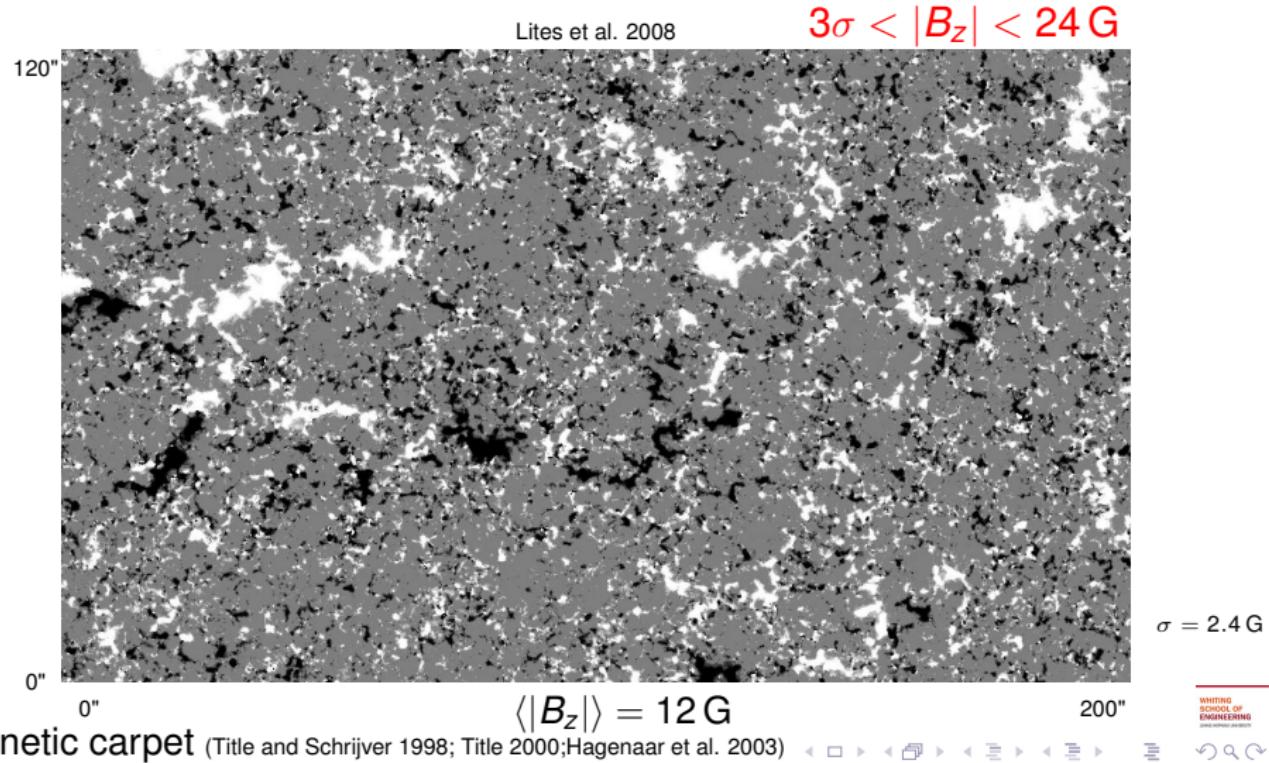
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Intra-network quiet-Sun magnetic field



Sun is a bit too messy

Simplify

- Very large scales, 1391 Mm
- 10^5 more velocity than magnetic scales
- Mysterious ~ 22 yr global dynamo
- Strongly stratified, compressible medium
- Little recirculation
- Ionization/radiation

The MURaM code (Vögler et al. 2005; Vögler 2003)

Realistic magnetoconvection

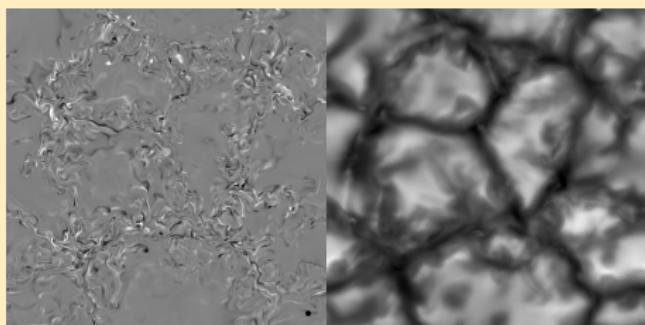
- Strong stratification
- Fully compressible
- Partial ionization
- Radiative transfer
- Open lower boundary

(vertical upflows, $\frac{dv}{dz} = 0$ for downflows; B_{hor} not advected
into box)

- High plasma- β
- No rotation

B_z & brightness

The MURaM dynamo (Vögler & Schüssler 2007)

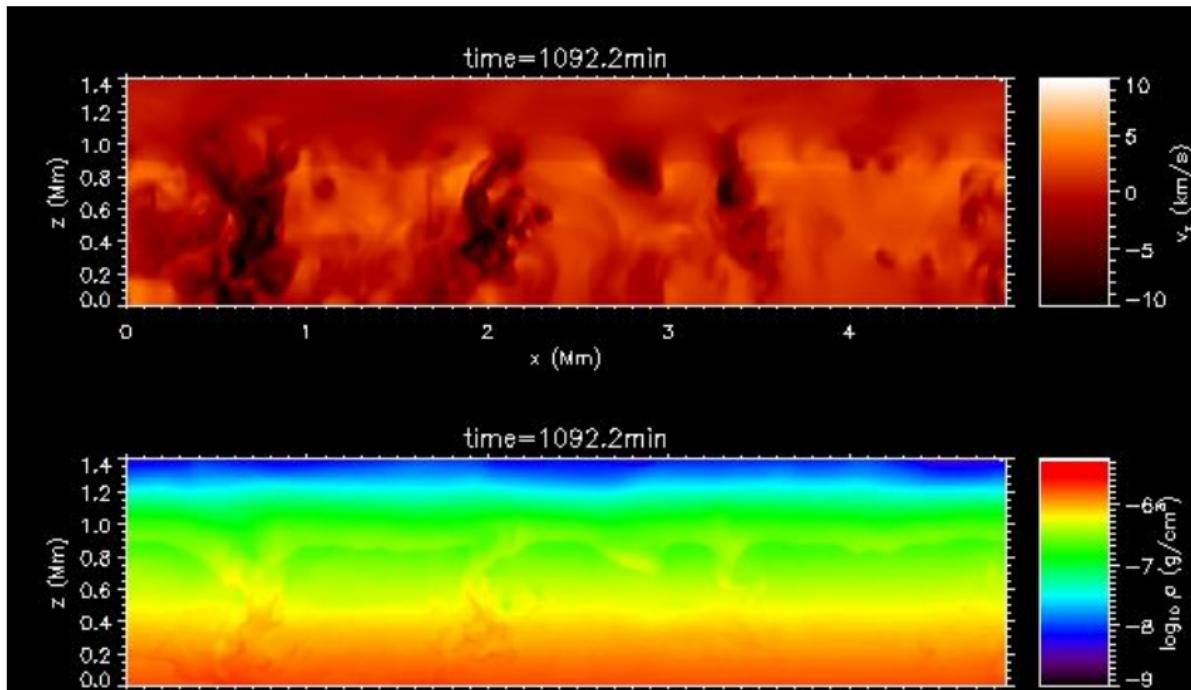


5 × 5 Mm

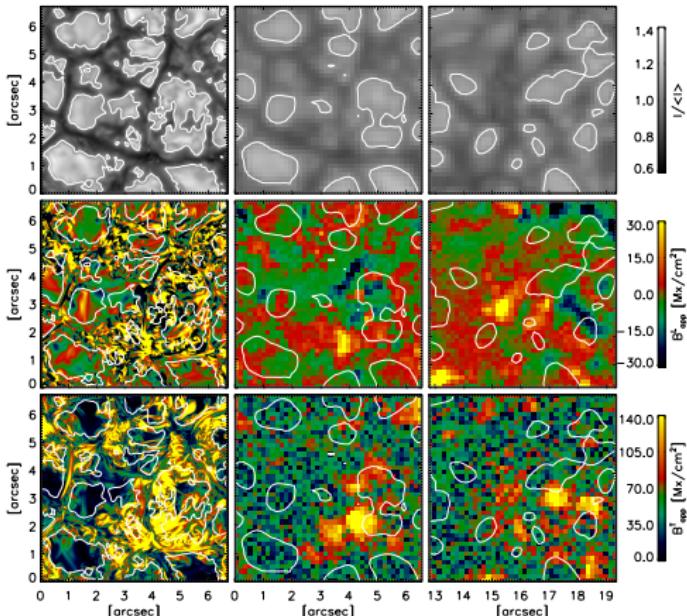
- Reversed granulation (Cheung et al. 2007)
- Granulation intensity contrast (Danilovic et al. 2008)
- Ratio of vertical to horizontal fields (Schüssler & Vögler 2008)

Messy solar convection

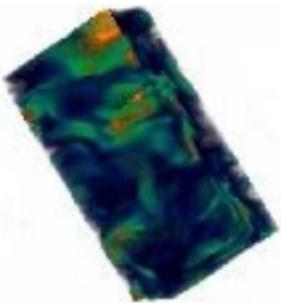
Run 1



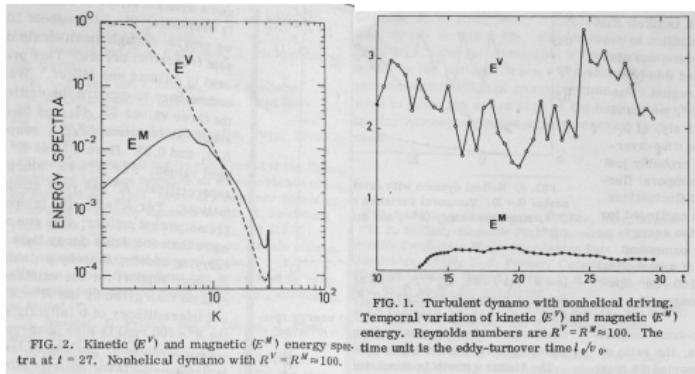
MURaM dynamo looks like the Sun (Danilovic et al. 2010)



Homogeneous, isotropic dynamos – well known



Ponty et al. 2005



$$N^3 = 64^3, Re_M \approx 100 \quad \text{Meneguzzi et al. 1981}$$

Many studies of small-scale dynamo (SSD)

Childress & Gilbert 1995; Maron & Cowley 2001; Heitsch et al. 2001; Schekochihin et al. 2004; Maron et al. 2004;

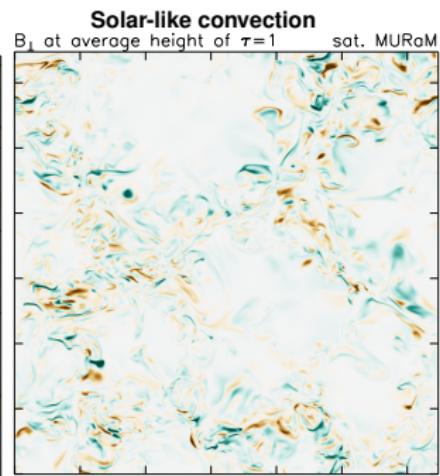
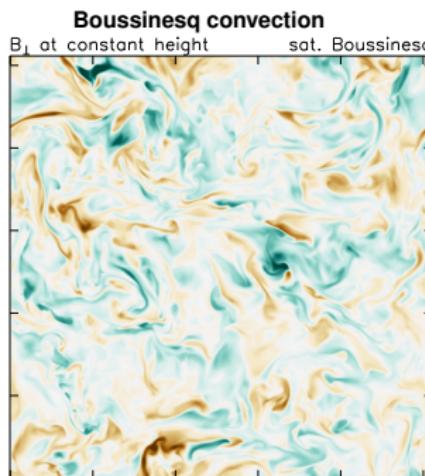
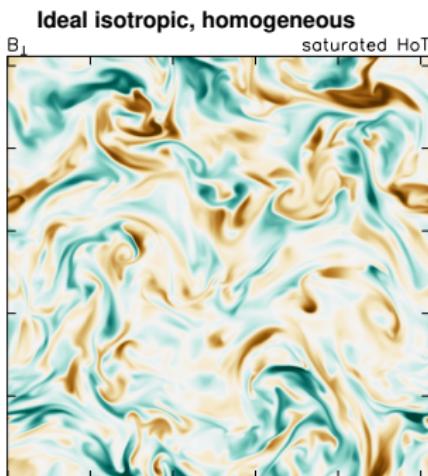
Ponty et al. 2005; Schekochihin et al. 2005; Mininni 2006; Ponty et al. 2007; Iskakov 2007, ...

Compare 3 dynamos

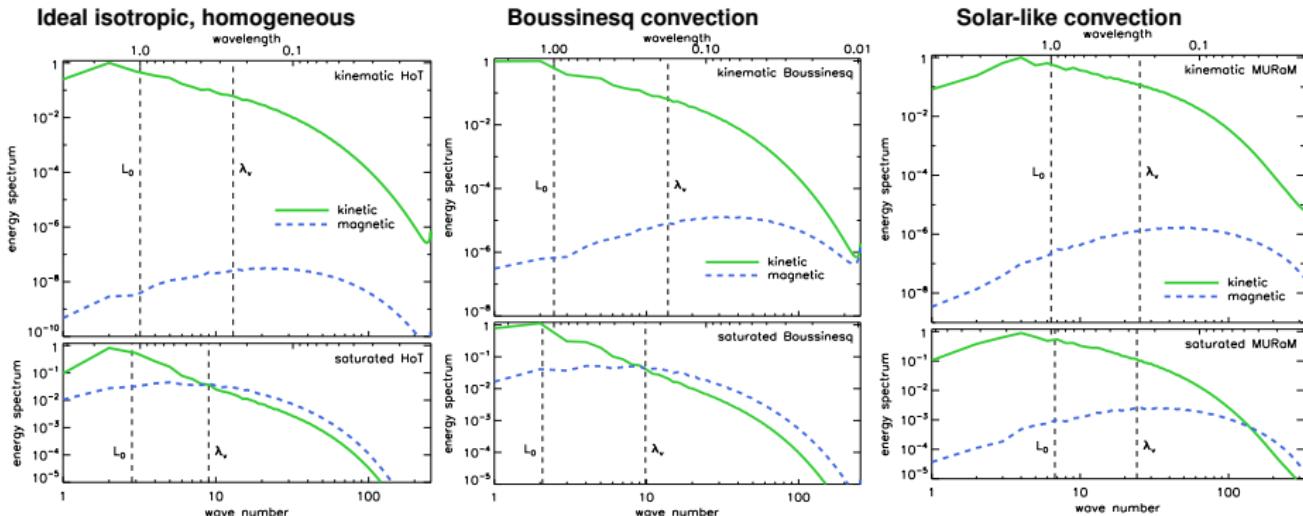
Incrementally add realistic physics

- Incompressible, Homogeneous, isotropic Turbulence (HoT) with Ornstein-Uhlenbeck (Langevin equation) forcing at $k \in [2, 3]$
- Boussinesq (incompressible) convection (anisotropic)
- Strongly stratified compressible, partially-ionized, radiative convection (MURaM)

Visually



Spectrally



Shell-to-shell transfer analysis

(Alexakis et al. 2005, Mininni et al. 2005)

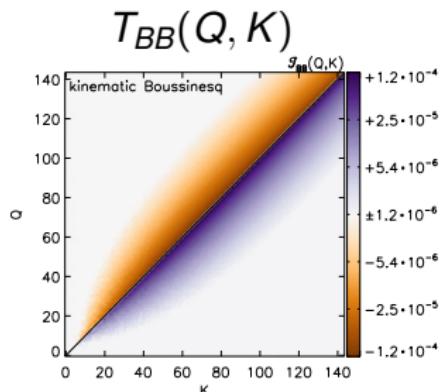
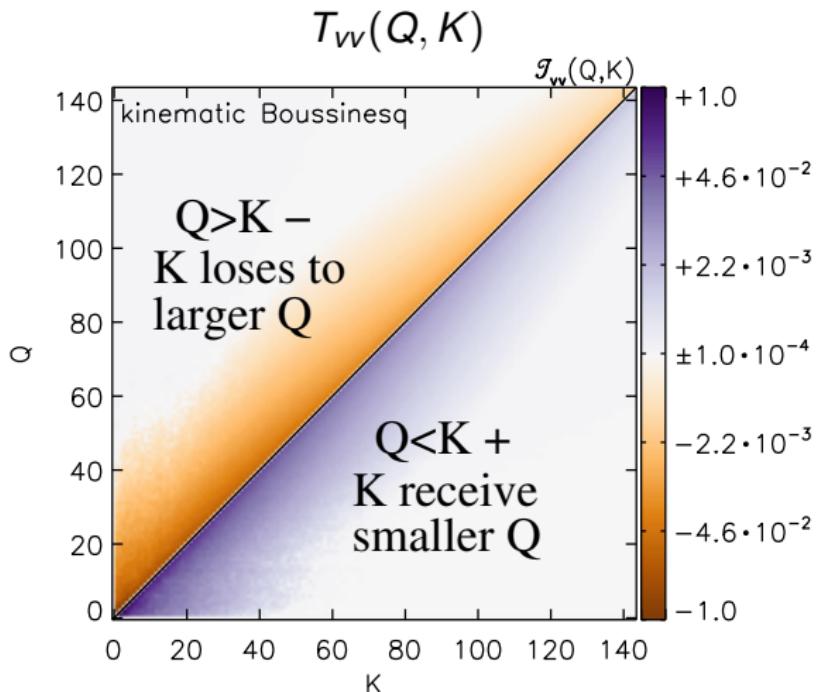
$$\mathbf{a}(\mathbf{x}) = \sum_K \mathbf{a}_K(\mathbf{x}) \quad K < |\mathbf{k}| \leq K + 1$$

$$\begin{array}{ll}
 \partial_t \langle \frac{1}{2} \mathbf{v}_K^2 \rangle & T_{vv}(Q, K) \\
 \langle \mathbf{v}_K \cdot [\partial_t \mathbf{v}_K] & + \mathbf{v} \cdot \nabla \mathbf{v}_Q + \nabla P = \\
 & \overbrace{\mathbf{B} \cdot \nabla \mathbf{B}_Q}^{T_{BvT}(Q, K)} + \dots \rangle \\
 & \uparrow \\
 & \downarrow \\
 \langle \mathbf{B}_K \cdot [\partial_t \mathbf{B}_K] & T_{BB}(Q, K) \\
 \partial_t \langle \frac{1}{2} \mathbf{B}_K^2 \rangle & + \mathbf{v} \cdot \nabla \mathbf{B}_Q = \\
 & \overbrace{\mathbf{B} \cdot \nabla \mathbf{v}_Q}^{T_{vBT}(Q, K)} + \dots \rangle
 \end{array}$$

dissip dissip

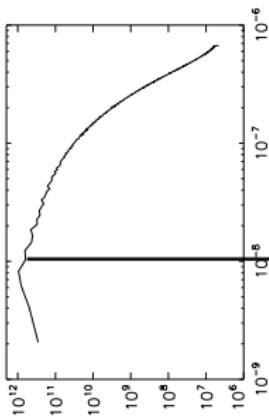
$$T_{vBT}(Q, K) = -T_{BvT}(K, Q)$$

Direct, local cascade



The dynamo mechanism

Kinetic Energy

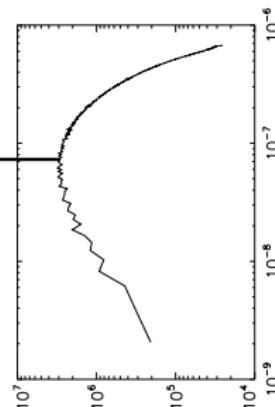


$$T_{vBT}(Q, K) = \mathbf{B}_K \cdot (\mathbf{B} \cdot \nabla) \mathbf{v}_Q$$



Q

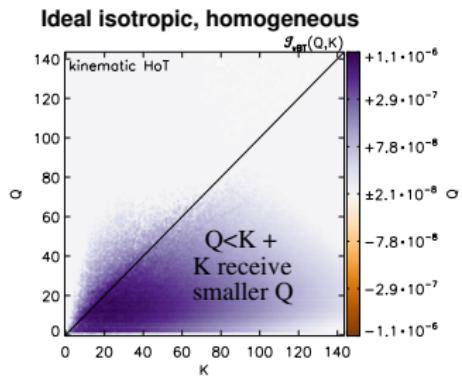
Magnetic Energy



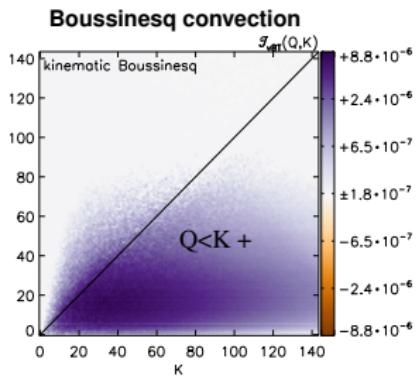
K

Same kinematic dynamo mechanism

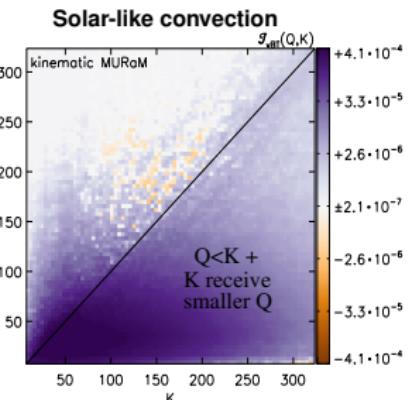
$T_{vBT}(Q, K)$



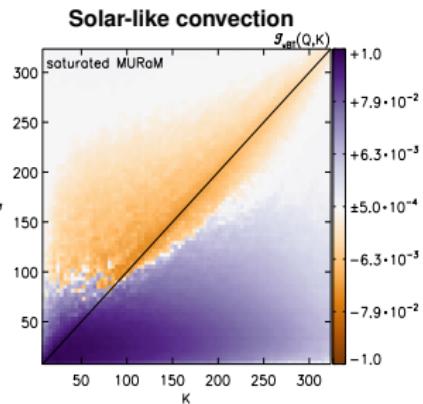
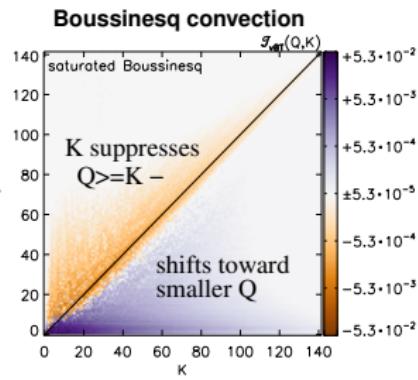
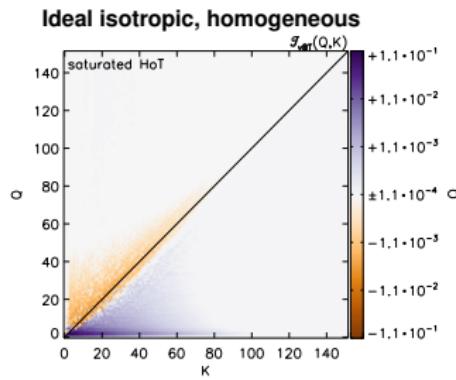
$T_{vBT}(Q, K)$



$T_{vBT}(Q, K)$



Same saturation mechanism



Conclusions

Pietarila Graham et al., *ApJ* **714**, 1606-1616, 2010

Ideal results extend to real systems

- Only one small-scale dynamo (SSD)
 - Independent of (isotropy) forcing
 - Same in the face of lots of messy physics
- SSD should work in the Sun as well
 - $P_M 10^{-2}$ OK for SSD (Ponty et al. 2005, Iskakov et al. 2007)
 - $P_M 10^{-5}$ for $\alpha - \omega$??? (Monchaux et al. 2009)
 - Strong stratification/little recirculation, partial ionization, radiation do not change SSD

Summary

Future work

- “Background” field & dominant source
 - “Compressive cascade”
 - Alfvénic turbulent induction
 - SSD
- Lower P_M